Load Frequency Control in an AC Microgrid

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Bachelor of Technology in Electrical Engineering

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CERTIFICATE

*This is to certify that the thesis entitled "**Load frequency control in an AC Microgrid**", submitted by **K Mahesh Dash (110EE0192), Makhes Kumar Behera (110EE0120)** and **Vamsi Krishna Angajala (110EE0201)** in partial fulfillment of the requirements for the award of **Bachelor of Technology** in **Electrical Engineering** during session 2013-2014 at National Institute of Technology, Rourkela. A bonafide record of project work carried out by them under my supervision and guidance.*

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DEDICATED TO THE ALMIGHTY AND OUR PARENTS

ABSTRACT

In the present scenario, due to the staggering increase in demand for electrical energy, system stability becomes an important concern. When electrical power demand increases, it creates unnecessary frequency oscillation and voltage oscillation in the power system, and hence a lot of pressure are put on it. The increase in the complexity of the power system and connection of various sources, renewable energy can be considered as one of the best alternative source. In our complex grid systems, now a days very much increase in the number of micro-grids (MGs), the existence of a sudden and random load perturbation, uncertainty in the parameter and due to variation in the structure, the operating frequency is not the same as the required frequency. For the purpose of reduction in the frequency deviation and maintaining balance between power generated and the load, our grid system requires an intelligent, sophisticated and easily controllable at optimized point. In this age obscure controllers are not efficient enough to facilitate a wide range of operation.

For this purpose, this thesis presents an integration of both fuzzy logic and conventional PI controller with various techniques for optimal tuning of our controllers in the AC micro grid systems. The tuning of PI controller and its control parameters are obtained from Ziegler-Nichols tuning method to optimized the parameter. The systems including the transfer function models are designed and simulated in a user friendly and most reliable MATLAB/Simulink environment.

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CHAPTER 1

INTRODUCTION

Introduction
Literature review
Motivation and Objective of the Thesis
Organization of the Thesis

1.1 INTRODUCTION

With the increase in demand for electrical power, the surge in the exhaustiveness of the main grid, due to inclusion of various genuine sources, Renewable energy sources (RESs) are one of the optional source. But Renewable sources pose the problem of stability with respect to generation. Also, Renewable energy sources have their own troublesome when it comes to the point of maintenance and security of the main grid in regard to the system voltage and frequency that is to be fixed and a proper regulation [1]. All this parameters are combined in one grid that will be called as Micro-grid (MG). The basic concept of micro grid was invented in 1998 by the Consortium for Electric Reliability Technology Solutions (CERTS) [4], [8].

For providing an adequate reliability and a good improve in the monetary and environmental point of view aspects of the system, the inclusion of MGs comes to the rescue of power systems. Photovoltaic panels (PV), Fuel cells (FCs), Wind turbines (WTGs), Diesel engine (DEGs), and battery for quick back-up in order to supply the power so that sudden power oscillation can be avoided and also these are part of a Micro Grid, which should be kept near the consumer side and connected with main grid in order to form a distributed generations (DGs).

1.2 LITERATURE AND REVIEW

Now in the present trend it is very much essential to inter-connect the grid so that the stability is going to be maintained and due to this the frequency will be stabilised. Now a days in the state of going simply to the distribution network, it is very much essential to go for incorporation of micro-grid. In order to avoid the power interruption and to maintain the reliability, it is very much needed to go for micro-grid. Now in the recent trend researchers are working in various system in order to have control over the frequency. Previously the frequency was being stabilised by ordinary PI controller but now a days that method is obscure [4, 5]. After a long days back fuzzy logic was invented and this is now very much used in designing the controller [4, 5]. The widespread use of fuzzy logic made the system more sophisticated and due to this the response time of the system become much faster as compared to the ordinary one.

After a long days later in early 1970's the introduction of the evolutionary algorithm was a prodigious attempt towards the stability of the non-linear system. At that time the discovery of Genetic Algorithm by *John Holland*, which was based on the evolution i.e. crossing of parents chromosome pair in order to form a child and so on for the next generation; the concept made a revolution in field of theoretical science in order to get an optimised value of any non-linear system. After that, the researcher put their thoughts to implements the concept in Micro-grid and to optimise the design of the controller [6].

After that, in 2001 *et.al Yoshibumi Mizutan* published his paper regarding load frequency control in IEEE journal. After the discovery of GA, researchers again went for most sophisticated algorithm so that they can a solution which is closer to the actual solution and, as a result, *Sir James Kennedy* for the first time in 1995 invented Particle Swarm Optimisation (PSO) which was supposed to give better performance in order to optimise the solution. After that many researchers, made an attempt to implement this in order to stabilise the frequency in a Micro-grid [7]. After that the implementation of both fuzzy and evolutionary algorithm made the system more stable and closer towards the exact solution [8]. Now a days researchers are still doing research in order to stabilise the frequency and voltage at a time. Now a days the algorithm like bacteria foraging and radial basis function neural logic network are making the design of the controller more and more sophisticated and much reliable in order to stabilise the frequency in a micro-grid.

Researchers are also looked upon the time delay effect on micro-grid and hereby the smoothing effect of the micro-grid can be established. In order to analyse properly about the LFC in a micro-grid one isolated micro-grid is being considered, and it is being studied. In order to make an infinite grid system at first two area controls are being performed and now a days multi-area micro-grid connection are also made in order to make the system more and more rigid [15].

1.3 MOTIVATION AND OBJECTIVE OF THESIS

Load frequency control in a Micro-grid is now a day's one of the booming area of research; 30th July 2012 is one of the memorable day where one of the severe blackout occurred in the great electrically inter-connected nation like India. In the year, two consecutive blackout occurred in this great country. At first in 1965 the northeast blackout which occurred at various part of Ontario in Canada and United States and more than crores of people remained in the dark. Researchers tried to find out the cause for this type of blackout and the new concept of load frequency control was developed on that day.

In India due to the hazard of July and August, the Indian scientist also become more serious towards the Load frequency control. One year, before it was only the main grid system and distribution system, was there in all over the world, but slowly people invent the concept of micro-grid which is connected by local controller and at the time of power scarcity the local source like renewable energy source will provide power to the system and no power interruption will be there and due to this reason the reliability is going to be maintained [7]. The use of renewable energy here made the system much more sophisticated, rigid and stable and was confined as one of the booming area of research. If a sudden main grid failure is there then still the load is getting power from the other micro sources which is given to the load and the power from the main grid will be cut off [11].

The main objective of the thesis are:-

- To build of a system which consist of different micro-sources like PV cell, wind turbine generator, Fly wheel system, battery system, diesel generator by using MATLAB based SIMULINK models.
- The use of PI controller of conventional type in order to stabilise the frequency when the load power demand will increase or decrease for static load.

- After the use of the conventional one then we use higher version of the controller for more efficient performance. For better performance than the conventional one, fuzzy PI controller is used.
- After the use of static load, the use of dynamic load which is closer towards the realistic and that's why here a 5th order Induction motor model is considered as load. The induction motor model was found out by state space averaging method (SSA).
- After that an analysis between the two controller and for this the integral square error (ISE) and integral absolute error (IAE) are calculated.

1.4 ORGANISATION OF THESIS

- CHAPTER 1- This chapter comprises of introduction, motivation & objective of the project along the literature review of "Load frequency Control in an AC micro grid."
- CHAPTER 2- this chapter comprises of system model and its description, PV model and its design, wind turbine model, and various energy storage system.
- CHAPTER 3- This chapter will give an idea about the load frequency control and the secondary tuning method. Here the use Zeigler-Nicholas Method is used for the tuning of the micro grid.
- CHAPTER 4- this chapter will give an understanding of fuzzy logic implementation and its control. Also the very designing model and use of static and dynamic load is also described here.
- CHAPTER 5- Here during the working of project the Terkera substation data was taken and it is being implemented. Hereby the results are being analysed properly.
- CHAPTER 6- In this chapter the conclusion and future work has been discussed.

CHAPTER 2

FREQUENCY CONTROL STUDY IN A TYPICAL MICROGRID SYSTEM

System Description
Photo Voltaic Panel
Wind Turbine Generator
Energy Storage System

2.1 SYSTEM DESCRIPTION

For the project, an AC micro-grid is assumed to consist of group of distributed loads and distributed energy low voltage sources, such as PV panels, Wind turbine generators (WTGs), Diesel engine generators (DEGs), Fuel cells (FCs) and energy storage devices such as Flywheel energy storage system (FESS) and Battery energy storage system (BESS). The simplified MG architecture is shown in fig 1-1.

AC sources like DEG and WED are synchronized and DC sources like PV panels, FCs and Energy storage systems are integrated to the AC Micro grid structure using Power electronic interfaces. Each DG has its own individual circuit breaker, which disconnects it from system during lethal grid disturbances to protect it from the fault impact.

The MG model is an isolated Hybrid Renewable power generation model. Detailed in corresponding clauses are shown in the figure 1.1 where the local loads and controllers are connected [4].

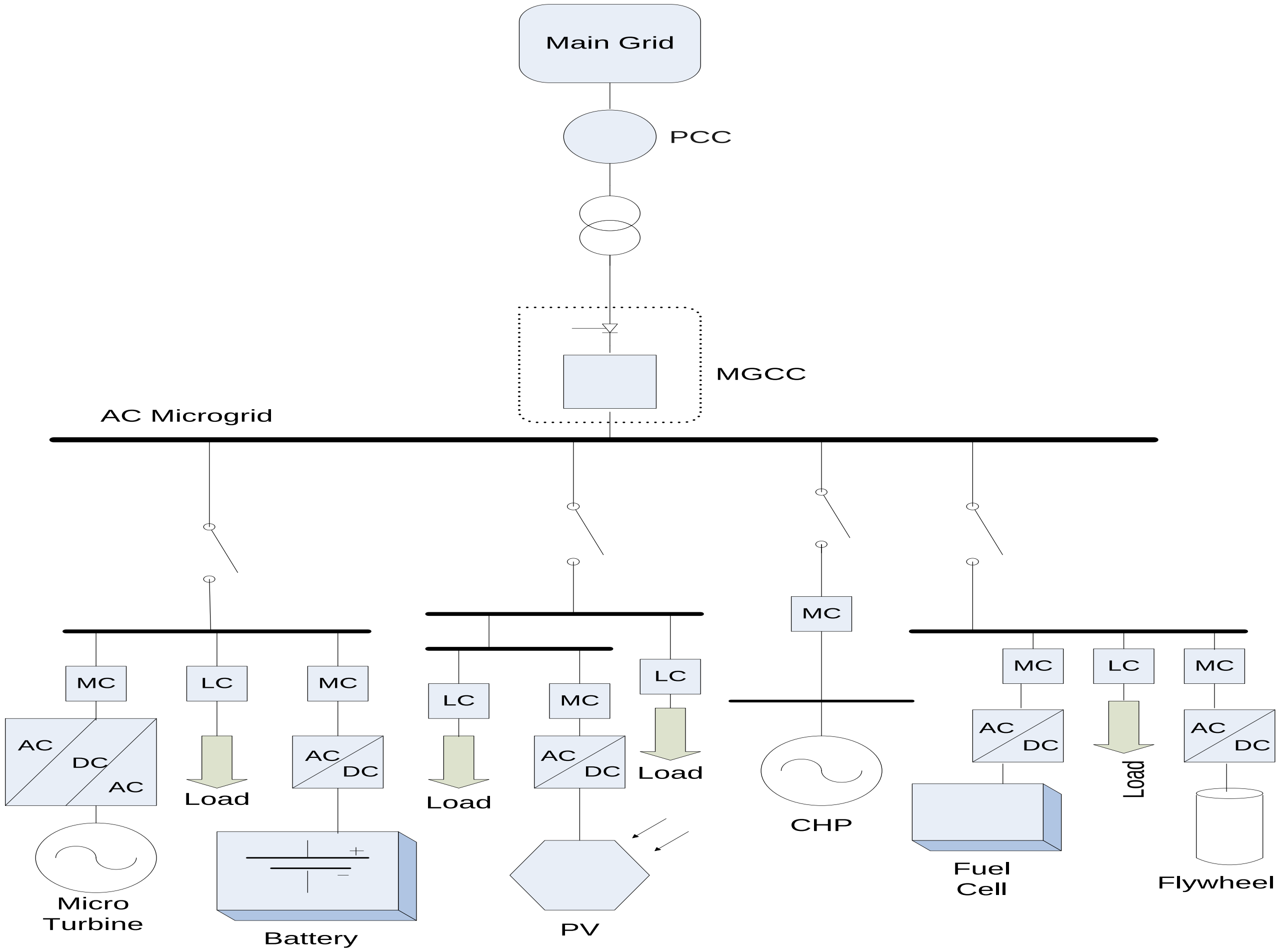

Fig. 1.1. Simplified AC MG structure

2.2 PHOTO VOLTAIC PANEL

PV cells generate power from semiconductors upon illumination. As long as light is incident on the solar cell, power is generated. The equivalent circuit can be represented by Fig.1-2. Practically in solar cell there is voltage loss occurrence due to boundary and external contact which corresponds to the shunt resistance (RS), also a small leakage current is produced due to parallel resistance (RP). The PV panels datum are considered [9] and its values are given in the table 1.1.

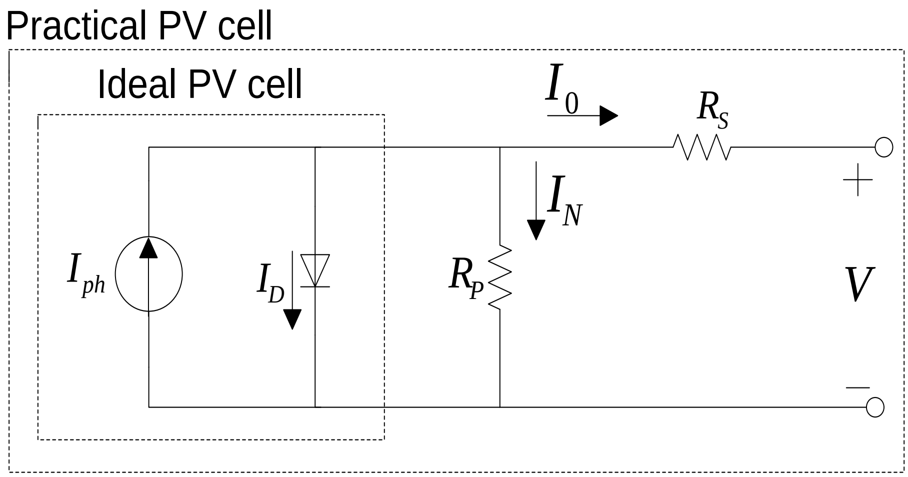

Fig. 1.2. Equivalent Model of PV cell

The PV panel [9], [10] simulation model is based on the current at the output of the PV model and its equation is given as (1).

$$I_0 = I_{ph} - I_r.\left[e^{q.(V+I_0.R_S)/\eta.k.T} - 1\right] - \frac{V + I_0.R_S}{R_P} \qquad (1.1)$$

Where: V is the output PV voltage; Iph the photocurrent; Ir the saturation current; q the electron charge(1.6x10-19C); η the quality factor of p-n junction; T the temperature(0K); k is the Boltzmann constant (1.38x10-23J/0K). In order to get a null root, equation (1.1) can be modified when the current (I) becomes the real PV current. So (1.1) can be represented by its own function.

$$f(I_0) = I_{ph} - I_0 - I_r.\left[e^{q.(V+I.R_S)/\eta.k.T} - 1\right] - \frac{V + I_0.R_S}{R_P} \qquad (1.2)$$

With null initial value of current if certain numbers of iteration will be taken; then the final output result will be closer to actual result with a lesser error, which can be done by Newton-Rhapson method

$$x_{n+1} = x_n - \frac{f(x_n)}{f'(x_n)} \qquad (1.3)$$

Thus the derivative of (1.3) will be (1.4)

$$f(I) = -1 - I_r\left[e^{q.(V+I_0.R_S)/\eta.k.T}\right]\frac{q.R_S}{\eta.k.T} - \frac{R_S}{R_P} \tag{1.4}$$

Electrical parameters of the PV [9]

TABLE- 1-1 PV MODEL DATA

Maximum Power	Pmax = 30kW
Voltage at MPP	VMPP = 34.5V
Current at MPP	IMPP = 4.35A
Open Circuit Voltage	Voc = 43.5V
Short Circuit Current	Isc = 4.75A
Temperature Coefficient of Isc	0.065 A/oC
NO of series Cell	06
NO of parallel Cell	10

Figure 1-3 show the non-linear power characteristics of the above PV equations along with the maximum power points at constant temperature and irradiation respectively.

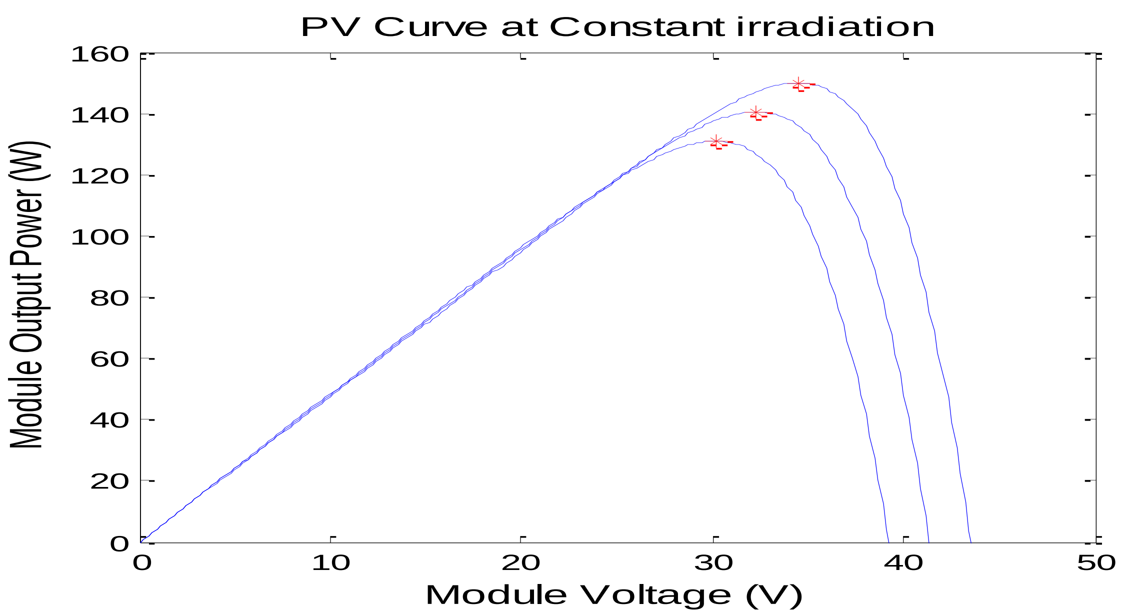

Fig 1.3. PV curve at constant irradiation (1000 W/m2) for temperature values of 328K, 313K, and 298K (from top to bottom)

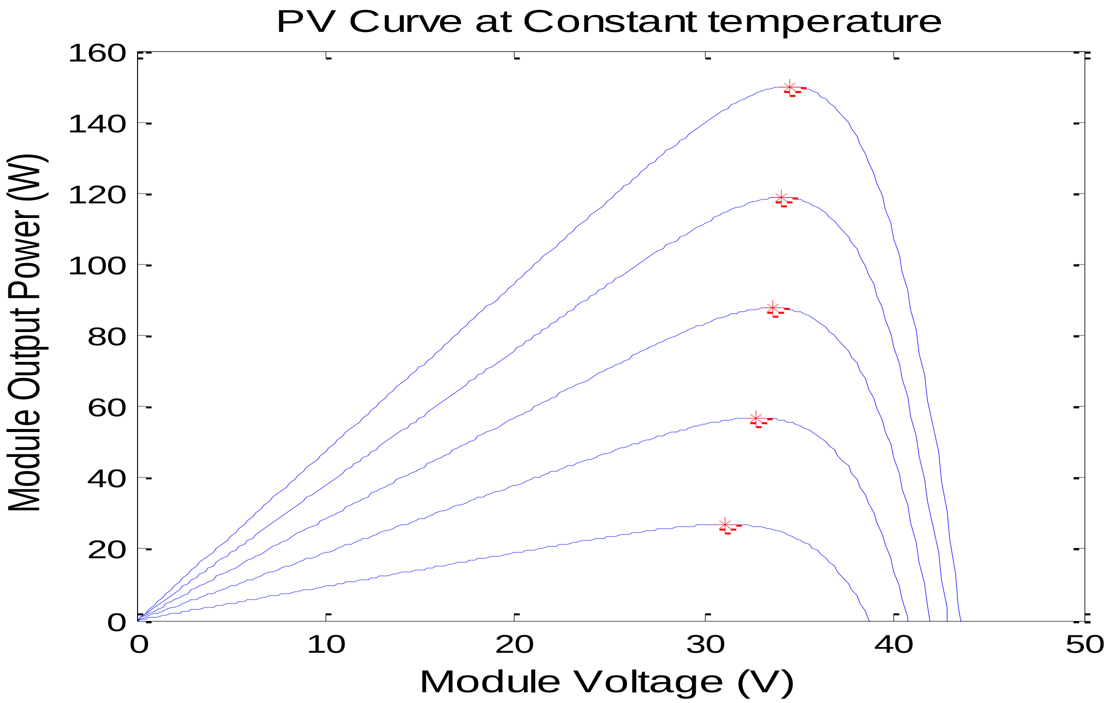

Fig. 1.4. Right side curves are at constant temperature of 298K and irradiance values of 200,400,600,800 and 1000W/m2 (from top to bottom).

2.3 WIND TURBINE GENERATOR

In the present system's Wind Energy extraction System, wind turbine is modeled as in [11-12]. The generated power in the WTG is related to the wind velocity(V_W). The rotor mechanical power(P_W) produced by the wind turbine is given by equation (1.5)

$$P_w = \frac{1}{2}\rho A_r C_p(\gamma,\beta)V_w^3 \tag{1.5}$$

This equation is used to model the performance coefficient of the wind turbine as a function of tip speed ratio and blade pitch angle as given in Equation (1.5). It is based on turbine characteristics in [11]. The tip speed ratio is defined as the ratio of the speed at the tip of the blade to the wind velocity.

$$C_p(\gamma,\beta) = C_1\left(\frac{C_2}{\gamma_i} - C_a\beta - C_4\right)e^{\frac{-C_5}{\gamma_i}} - C_6\gamma \tag{1.6}$$

Equation for γ_i is given as equation (1.7). The coefficient C_1 to C_6 are:- C_1 =0.5176, C_2 =116, C_3=0.4, C_4=5, C_5=21 and C_6=0.0068

$$\frac{1}{\gamma_i} = \frac{1}{\gamma + 0.08\beta} - \frac{0.035}{\beta^3 + 1} \tag{1.7}$$

The wind turbine model considered in the study is with WT having prototype as given in [11]. For a typical wind turbine blade radius here is taken as 18m, and the rotational speed of the blade is taken as 3.14rad/s. The air density ρ is 1.25kg/m3 and swept area of blades is considered as A_r is 1018 m^2. By taking the above parameters into consideration, the following Table 1-1 is constructed which shows the mechanical output at different speed with different tip ratio and its' corresponding power coefficient.

The wind model which is considered here for the purpose of the study is providing a rated output of 190kW. But actual rated output of WT is 216W at 10m/s, which simply states that it has a conversion efficiency of 88.3% approximately for the associated gear system plus generator. The cut-in wind velocity for the WT is 4.22m/s. A cut-out velocity of 18m/s is considered for the machine. For wind velocity of 10m/s up to 18m/s, blade pitch control can be done to achieve rated output of 216kW from the turbine. Wind turbine speed from 4m/sec to 10m/sec the power varies approximately linearly with the speed of the wind and after that due to stall control the power is going to be constant irrespective of the wind turbine speed and due to this the turbine is safe from the high wind speed.

Now after that if the wind speed is going beyond the speed of 18m/sec at that time the controller will force the turbine speed to come to zero and that moment the turbine will deliver no power and power cannot be extracted at that time. Here the important thing to be noted that due to the use of stall controller up to some level the power is going to be constant, irrespective of wind speed and beyond that speed the power delivered to the system will be zero but the turbine at that time will be rotated more than the rated speed. And this is done in order to save the turbine from damage from this type of high speed. The blade pitch control is achieved in the Simulink model through ‘look-up block’ characteristics curve i.e. output mechanical power versus wind speed for the study of WT, as shown in Fig 1-4.

TABLE 1-2

Wind Velocity (V_w)in m/sec	Tip Speed ratio (γ)	Blade Pitch angle(β) in degree	Coefficient	Mechanical Power output in watts(P_w)
4	0	0	0	0
4.22	13.4	0	0.0003	13
4.6	12.29	0	0.1572	9731
5	11.31	0	0.2786	22157
6	9.42	0	0.4418	60706
7	8.08	0	0.48	104740
7.191	7.86	0	0.4787	113244
8	7.07	0	0.4548	148130
9	6.28	0	0.4016	186233
9.5	5.95	0	0.371	202367
10	5.65	0	0.34	216287
11	5.14	0.7	0.2554	216287
11.5	4.92	0.796	0.2235	216287
12	4.71	0.864	0.1967	216287
12.5	4.52	0.911	0.1741	216287
13	4.35	0.939	0.1547	216287
13.5	4.19	0.951	0.1382	216287
14	4.04	0.948	0.1239	216287
14.5	3.9	0.933	0.1115	216287
15	3.77	0.906	0.1007	216287
15.5	3.65	0.87	0.091	216287
16	3.53	0.825	0.083	216287
16.5	3.43	0.773	0.0757	216287
17	3.33	0.712	0.0692	216287
17.5	3.23	0.64	0.0634	216287
18	3.14	0.55	0.0583	216287
19	2.98	0	0.0481	209819

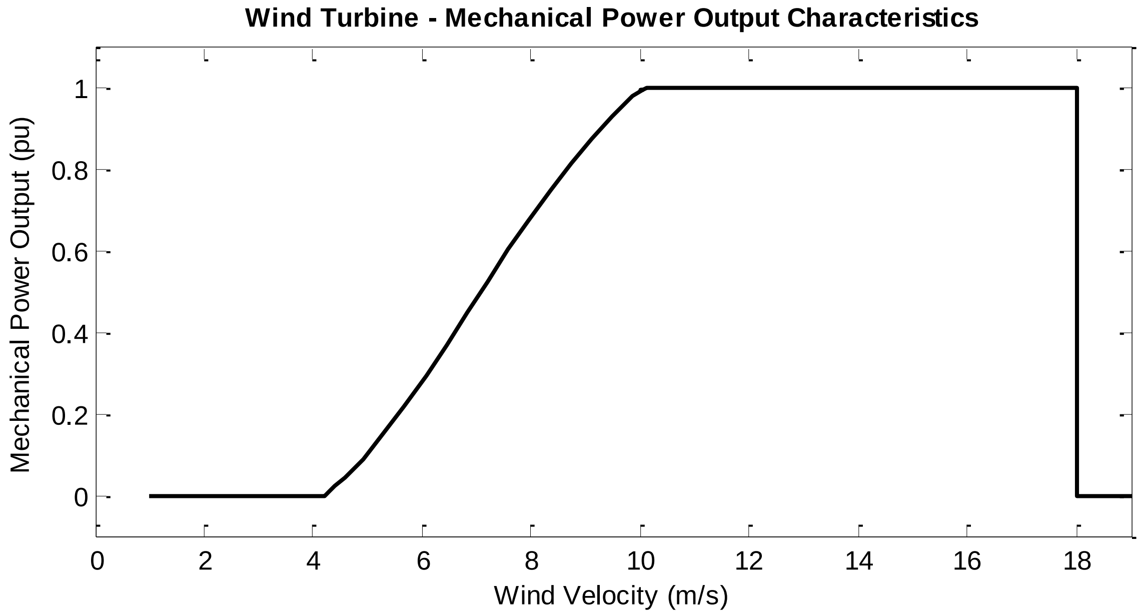

Figure. 1-5. Wind turbine Mechanical Power output characteristics

The simulations are done with assumptions of a wind velocity of 7.5m/s consistently during the simulation period and delivering a constant 100kW constant generation to the micro-grid.

2.4 ENERGY STORAGE SYSTEM

It is always essential to store and release the energy when there is an interruption of power and fluctuation occurs. The energy storage systems function in where there is a requirement of low and medium voltage distribution networks is needed [11]. Flywheel storage system (FESS) has very much high density of energy storage capacity, a greater ability to exchange power and more over free of pollution. High efficiency is one of the great advantage of this system and another great advantage is its design is long-lived pollution free. The FESS is included with micro-sources which may provide sufficient energy at the time of disturbances in the system. When it is combined with weak grid connected system and another power system which is completely isolated, supplied from Wind Turbine Generators and other different renewable energy sources, at that time the FESS will provide short-term energy storage which is essential for removing the fluctuations in wind power.

Battery energy storage system (BESS) [11] is also one typo which stores electric energy inform of DC as like in the battery and when it connects to the ac grid it needs a rectifier circuit, and a dc–ac inverter so that there is an exchange of energy will be there in between the AC system. In the last decade, the advancement in sealing procedure, recombinant of the lead-acid battery technology, and also the finest advancement in the compounds have increased the scope utility in term of economic and regarding the applications of the BESS. The used transfer function and the corresponding rated power of the flywheel and Battery storage systems are mentioned in the table 1-2 and 1-3 [4].

TABLE 1-3 POWER RATING OF VARIOUS SOURCES AND LOAD DEMAND

Rated Power (kW)	
Wind Turbine Generator	**110**
Photovoltaic	**40**
Fuel Cell	**80**
Diesel Engine Generator	**170**
Flywheel Cell	**55**
Battery Cell	**55**
Load Demand	**470**

TABLE 1-3 AC MICRO GRID PARAMETERS VALUES FOR SOURCES, POWER ELECTRONICS DEVICES

Parameter	Value	Parameter	Value
D (pu /Hz)	0.015	T_g (s)	0.08
2H (pu s)	0.1667	T_t (s)	0.4
T_{FESS} (s)	0.1	$T_{I/C}$ (s)	0.004
T_{BESS} (s)	0.1	T_{IN} (s)	0.04
T_{FC} (s)	0.26	R (Hz/pu)	3

For better understanding of frequency response of MG, a simplified frequency response model, is shown in Fig 1-5 [4].

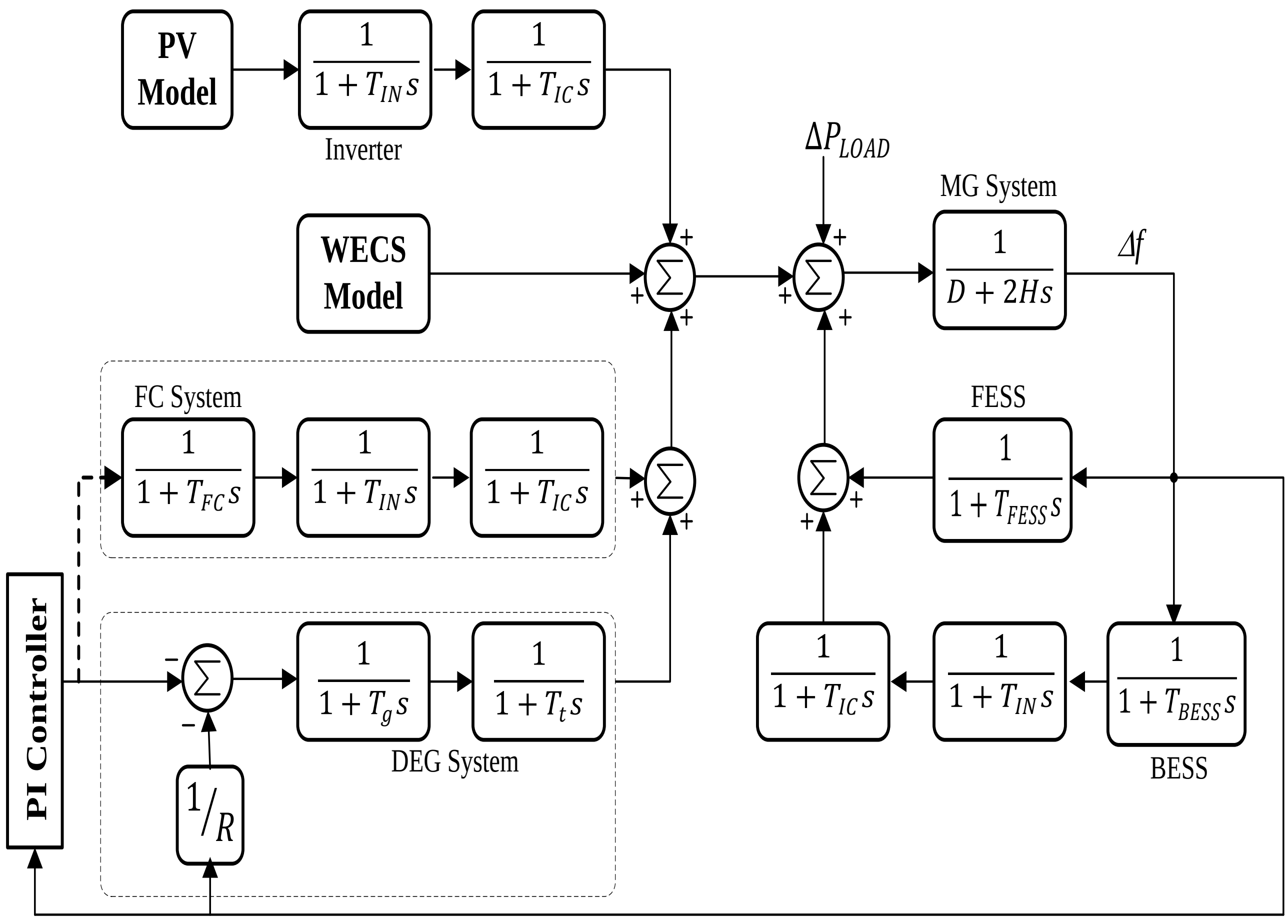

Figure.1-6 Frequency response model for the AC MG system

CHAPTER 3

FREQUENCY CONTROL AND SECONDARY CONTROLLER TUNING AND FUZZY IMPLEMENTATION

Secondary frequency regulation
Ziegler-Nicholas method
Fuzzy logic implementation
Static load modelling
Dynamic load modelling

3.1 SECONDARY FREQUENCY REGULATION

In the present system natural frequency regulation is provided by rotational inertia and the only rotational inertia source available is the DEG. DEG is provided with a PI based secondary controller. The same signal from this controller is used for FC system also. But it is not the same PI controller used in FC, because the droop used for DG will generate a separate error signal for the DG set which is not the same as that for the FC signal [4].

For the MG system, secondary controller is to be tuned for proportional gain (K_p) and integral gain (K_i) such that the frequency is restored to the specified nominal value under load or generation variation. In traditional power systems, tuning is done with a very small step load perturbation with respect to a pre-specified operating point. If the PI controller continuously keeps track of the changes occurring in the power system and change the K_p and K_i values accordingly in real time, optimal performance will be achieved. Fluctuation in load and generation are of compatible amount in terms of MG system capacity. Hence, response studies are done with a practical generation-load imbalance possible in the system, which is considered of the order of 20-40%. Frequency control action on the MG system is done by secondary controllers, which are tuned by the following two methods.

3.2 ZIEGLER-NICHOLAS METHOD

Ziegler–Nicholas is one of upmost method to design the tuning parameter of the PI controller, where at first the K_i (integral) and K_d (derivative) gains are required to set at zero value. Then the K_p (proportional) gain, has be increased (from zero) until it reaches to sustain oscillation and at that time the value of the gain will be the ultimate gainK_u, K_u when this oscillation will reach the time period will be T_u which is used to get the K_i, K_d and K_p values depending on which type of the controller we are using in the system [16].

TABLE1.4 ZEIGLER NICHOLAS CONTROLLER VALUES

Control Type	K_p	K_i	K_d
P	$K_u/2$		-
PI	$K_u/2.2$	$1.2K_p/T_u$	-
PID	$0.60K_u$	$2K_p/T_u$	$T_u Kp/8$

3.3 FUZZY LOGIC IMPLEMENTATION

In order to have better performance, a better way for online tuning of the PI controller is by using fuzzy logic, as shown in fig 1-7. A fuzzy PI controller consist of two stages. Stage one is fuzzy system unit where frequency deviation (Δf) and the change of load power to the source power (ΔP) are taken as input variables and after that fuzzy rules are incorporated and as far as the mentioned rules, the output variables (proportional gain,K_p and integral gain,K_{i}) are calculated by the fuzzy set and supplied to the PI controller for tuning. An important thing needed to be considered here is that at the time of large number of loads, it is always difficult to calculate the difference of the power and frequency being fed to the fuzzy logic controller [8]. Hence, secondary frequency control is important and is calibrated by tuning the PI controller but in changeable operating condition it doesnot give an optimal solution.

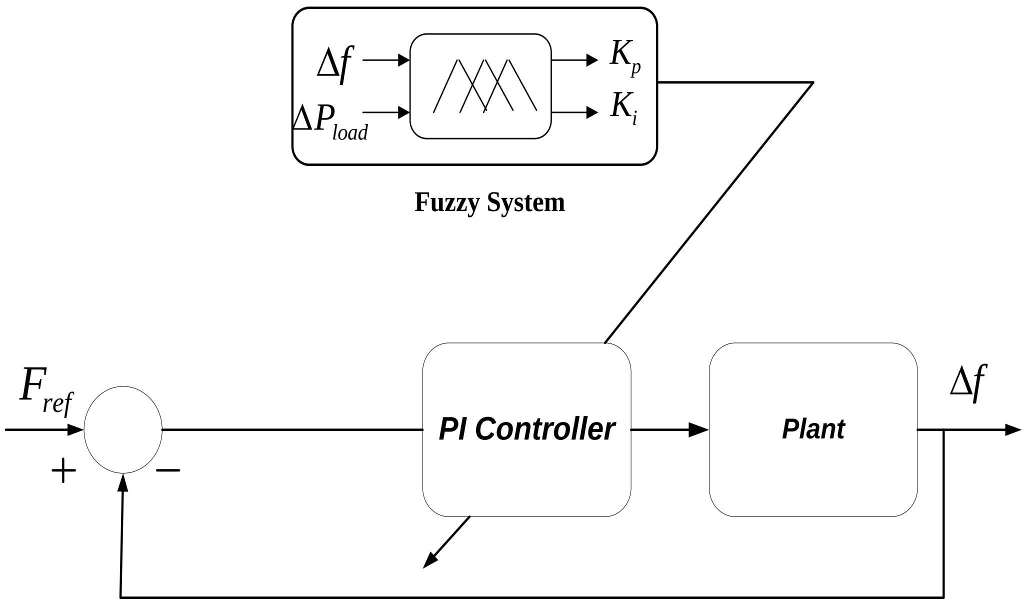

Figure.1-7. Secondary frequency control with fuzzy PI

TABLE 1-5 THE FUZZY RULES SET

ΔP/Δf	NL	NM	NS	PS	PM	PL
S	NL	NM	NS	PS	PS	PM
M	NL	NL	NM	PS	PM	PM
L	NL	NL	NL	PM	PM	PM

The membership functions of the input and output variables are categorised as *Positive Small (PS),Positive Medium (PM), Positive Large (PL), Negative Large (NL), Negative Medium (NM) and Negative Small (NS),*. The fuzzy logic codes are written in the *fis.file* in MATLAB where all 18 rules are written. Then *AND function* is used with *Mamdani* environment by using the Triangular Membership function. [4], [8]. Here in fuzzy based PI controller tuning operation, all the rules are mentioned based on the system consideration and while performing this, it is very much depends on the membership function which are being chosen by us, because of this thing all the rules has to select with a great consideration and should be bounded according to the input and output values. So in order to avoid this type of hindrance it is always advisable to choose other optimized algorithm with fuzzy logic so the more dependence thing will be eliminated.

3.4 STATIC LOAD MODELLING

For the modelling of the static load, it can be considered as the step input and according to the step input it is given as the load variable and the system simulation is being performed. At first the system is run through the conventional PI controller which is being tuned by the Zeigler-Nicholas method and after that it was being tuned by the fuzzy logic based tuning method and the corresponding results are being obtained. For more analysis, the various changing of the load are taken in to consideration and corresponding frequency deviation are shown in the Fig 1.21.

3.5 DYNAMIC LOAD MODELLING

For exact validation of the frequency deviation, an induction motor having a 5th order transfer function is considered as dynamic load. In order to build the transfer function model of the induction motor [13], state space average method is taken into account and the parameters are being referred as far as the reference [13], [8]. While designing the induction motor model it is very much important to consider its inertia. It has always one inertia and our system has also some short of inertia and when both the inertia are being combined at that time the system will be much more rigid and stable as compare to old static system. Now this model of induction motor is one type of real time example and all our practical loads are having some short of inertia.

The second important thing need to be considered that all the system has its own time constant and it is applicable to all the system but in the static load there is no time constant. Due to this time constant the system will always exhibit some short of time delay, other time delays are coming due to inclusion of wind turbine, diesel turbine, battery or flywheel. So whenever the induction motor torque changes the output power also changes accordingly and that change of power cause the change in the load demand. So here the step in the load torque is being performed and its corresponding output change is considered as load change and then it is applied to the system and its result are shown in the corresponding figure. Here the insertion of DG, the inertia constant (H) is coming and both are loaded it is always considered as one stable system.

Damping coefficient (D) is also one of important factor in consideration to the system. The presence of the induction motor load and the other damping coefficient which is coming due to turbine rotor mass which are accumulated and finally giving an effective damping factor which is higher than the previous one. Due to this increase in the damping and inertia parameter the overall system will be very rigid and stable. And due to this the frequency deviation is this type of dynamic load is quite less as compare to the static one [13], [8]. Here, for static and dynamic load, various step changes in loads are considered and its corresponding frequency deviation are depicted in Fig.1.8, 1.9 respectively. From the above result it is always being found that the fuzzy logic tuned PI controller is providing better performance as compare to the other one.

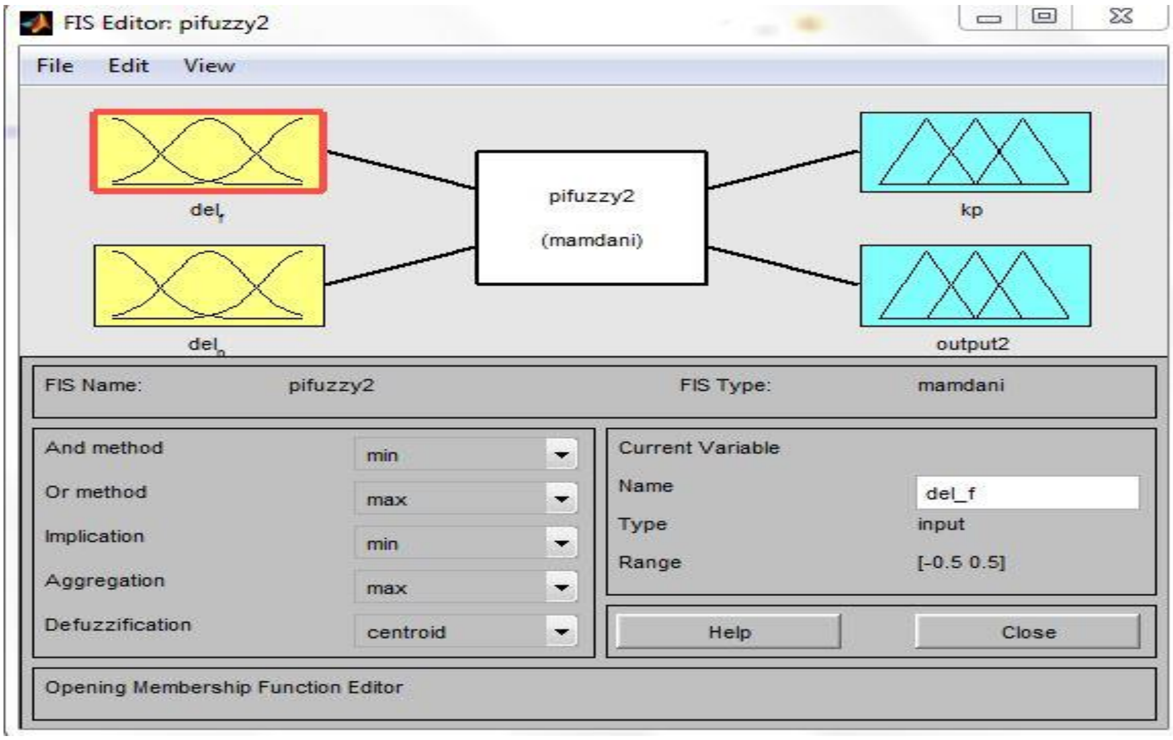

Fig 1.8: Fuzzy Logic Set

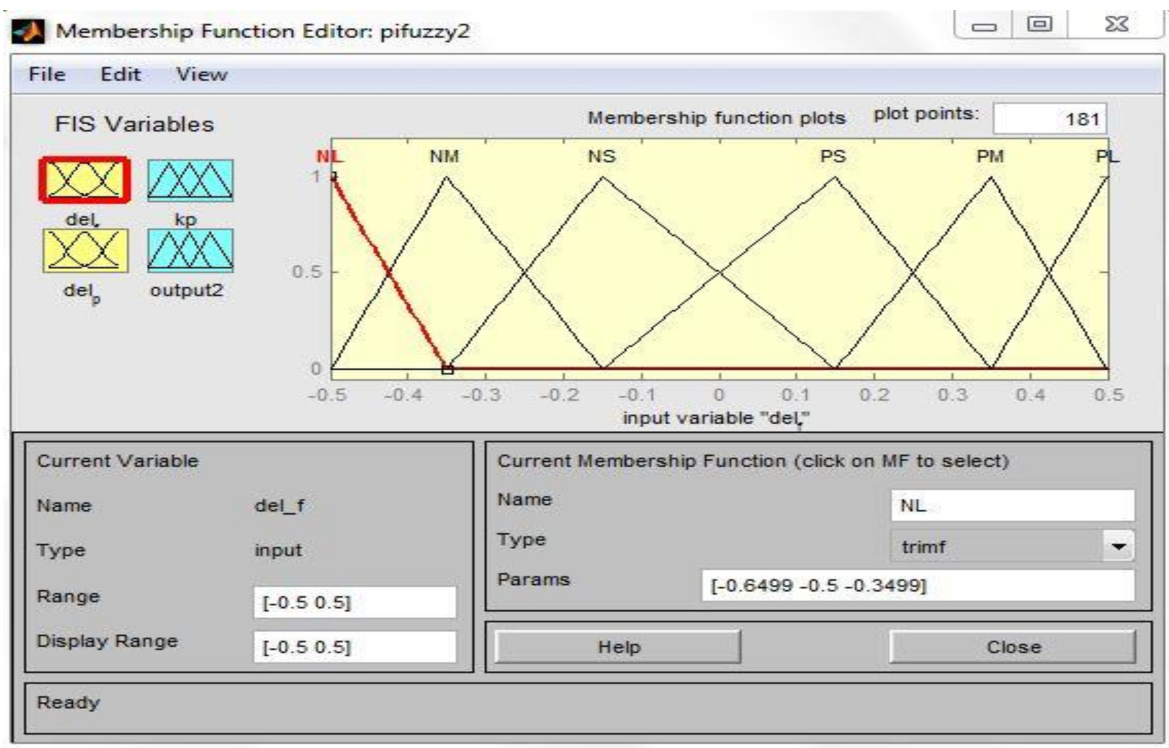

Fig 1.9 Fuzzy Logic input membership function (del(f))

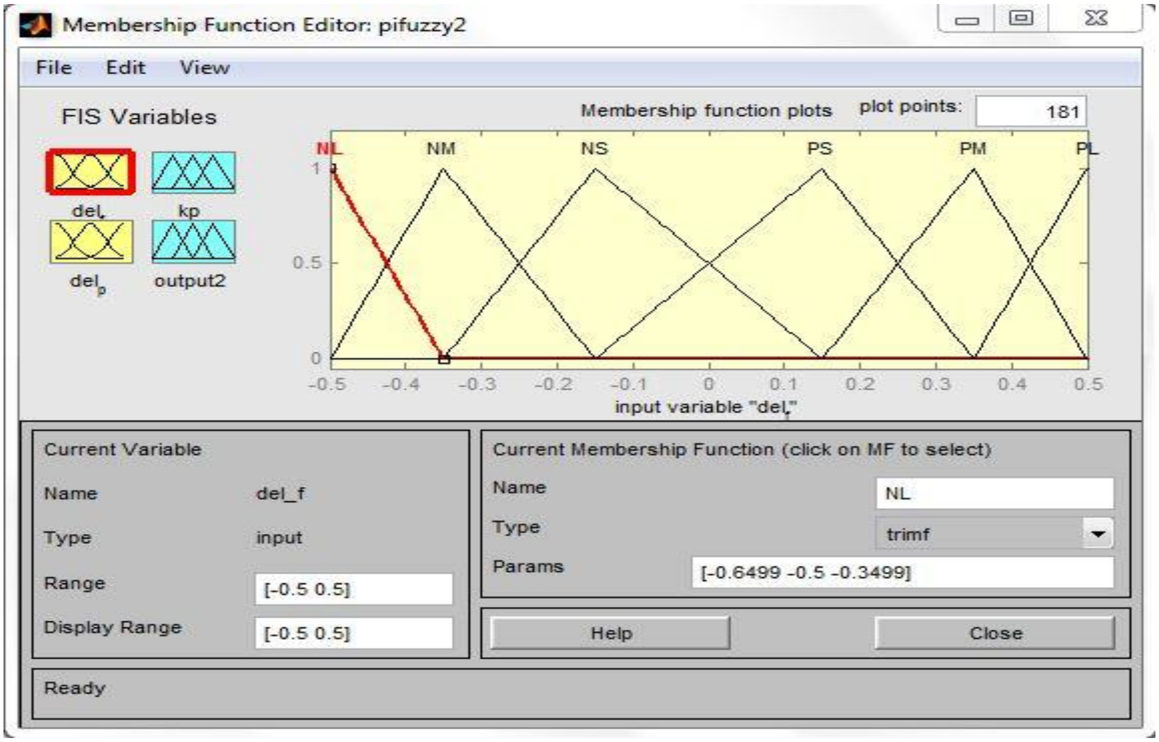

Fig 1.10 Fuzzy Logic input membership function (del (P_L))

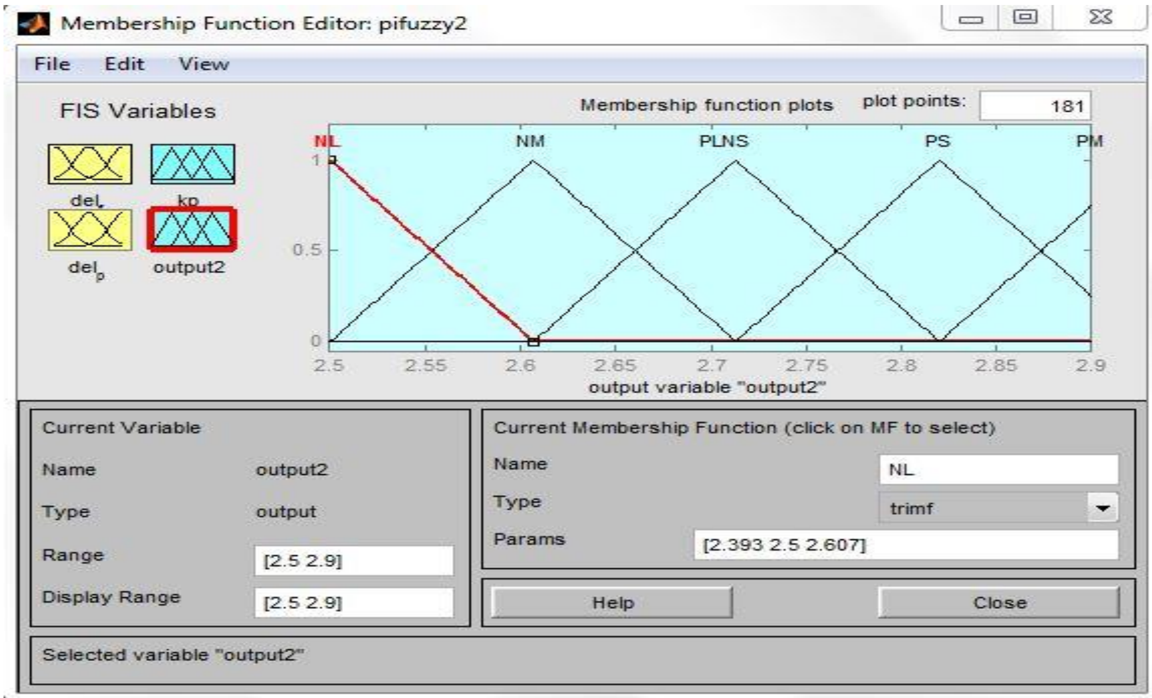

Fig 1.11 Fuzzy Logic output membership function (kp)

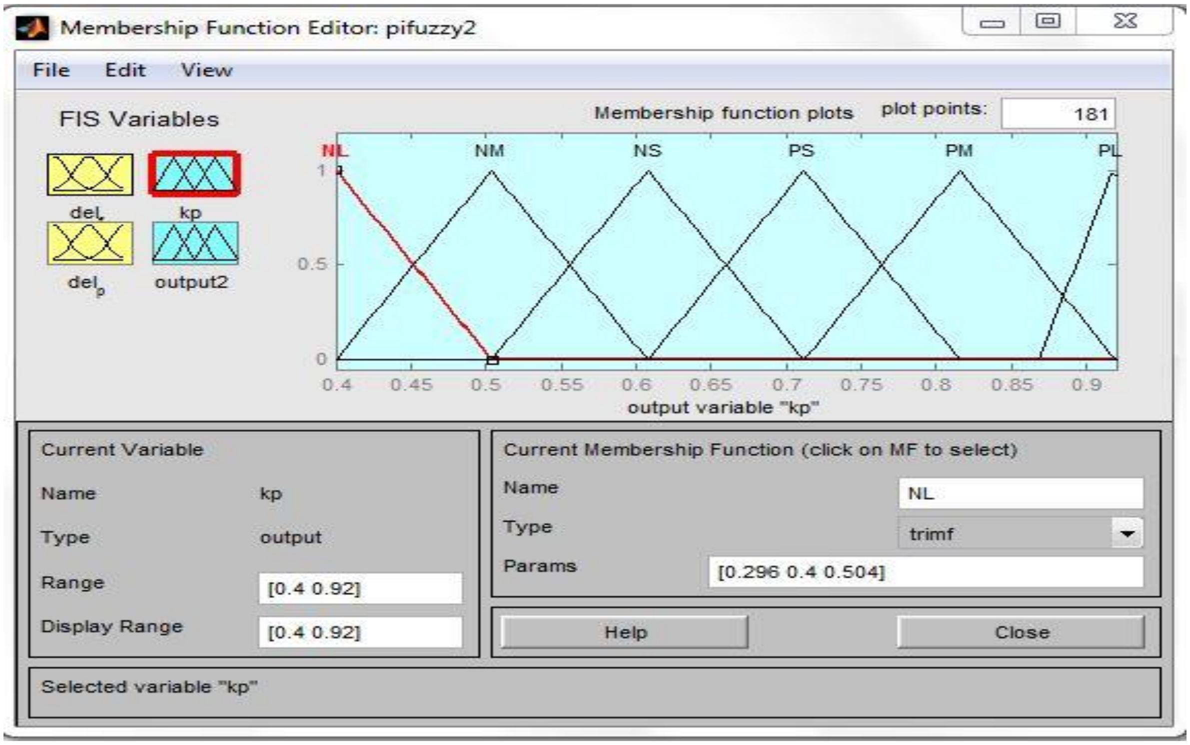

Fig1.12 Fuzzy Logic output membership function (k_i)

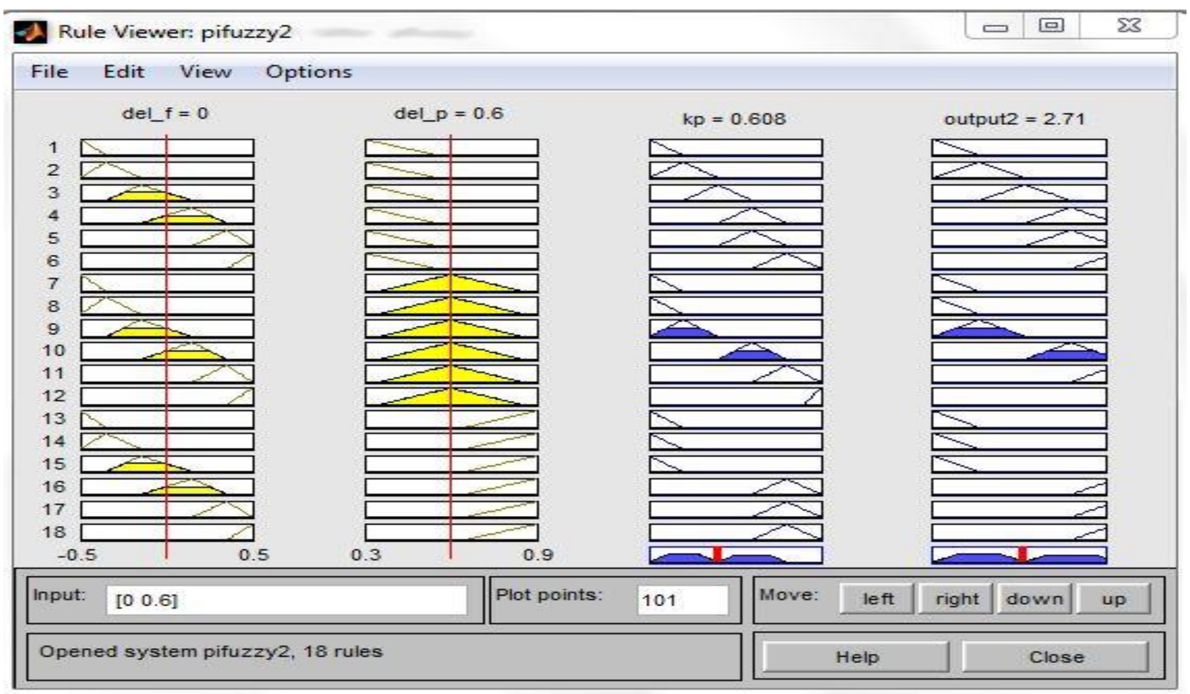

Fig1.13 Fuzzy Logic input/output membership function with graphical rules

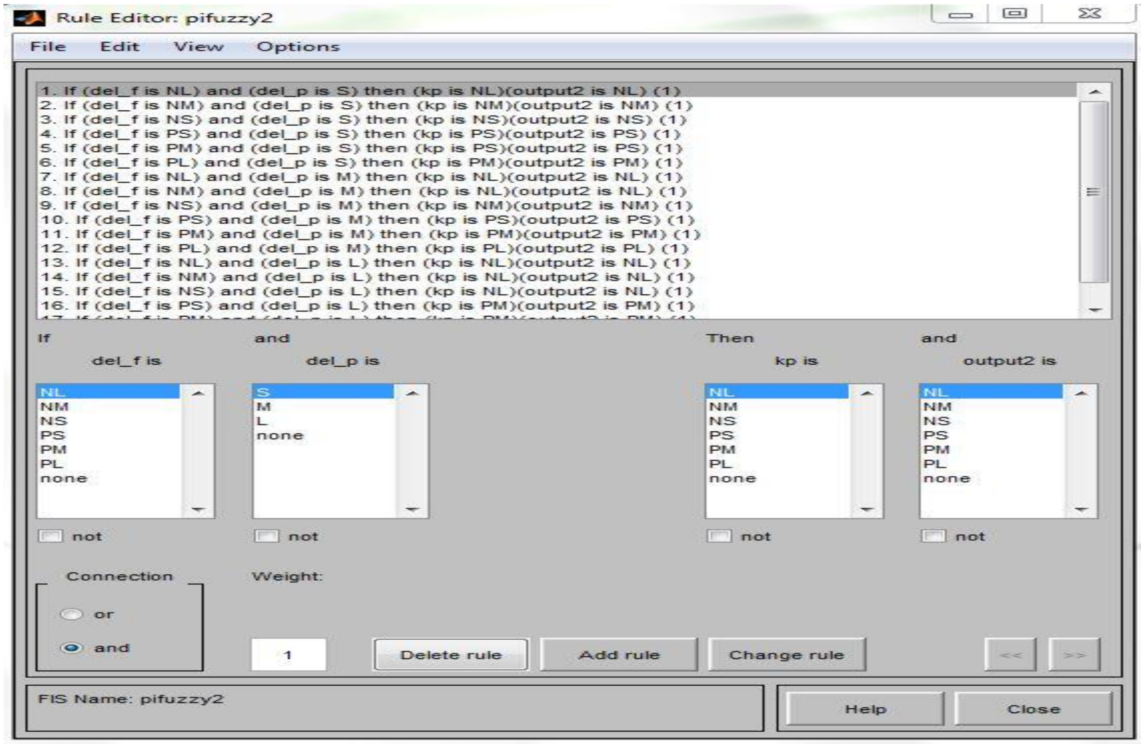

Fig1.14 Fuzzy Logic input/output membership function with rules

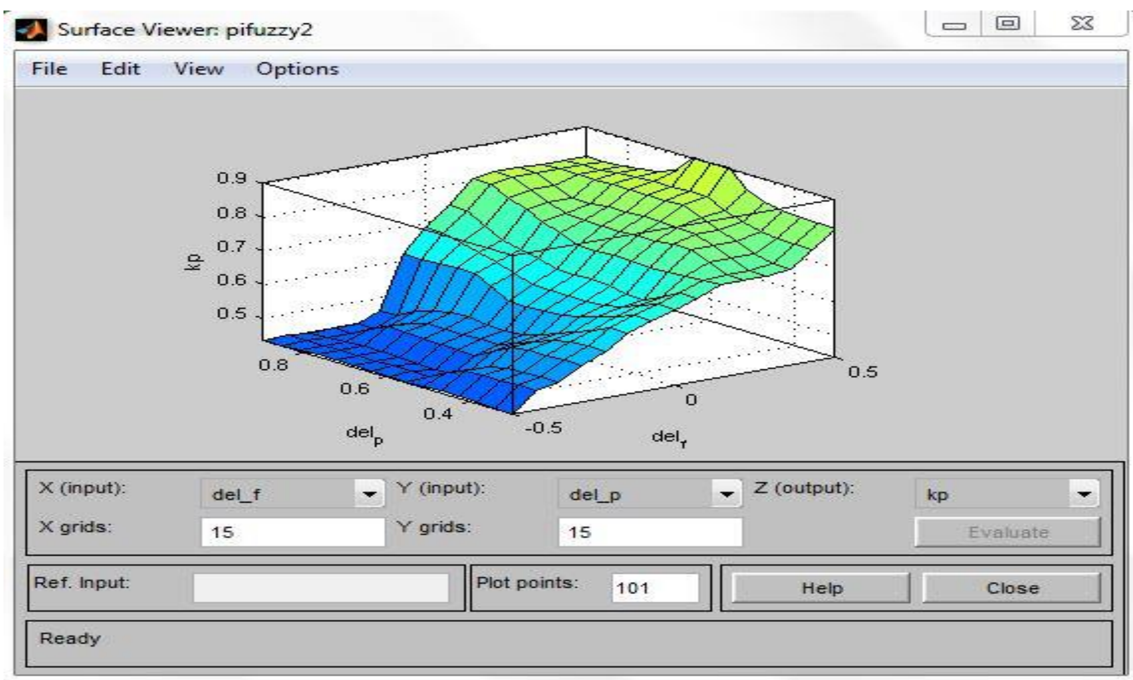

Fig1.15 Fuzzy Logic three dimensional surface function representation

CHAPTER 4

RESULTS AND DISCUSSION

Simulation results of LFC
Analysis and result
Discussion

4.1 SIMULATION RESULT OF LFC

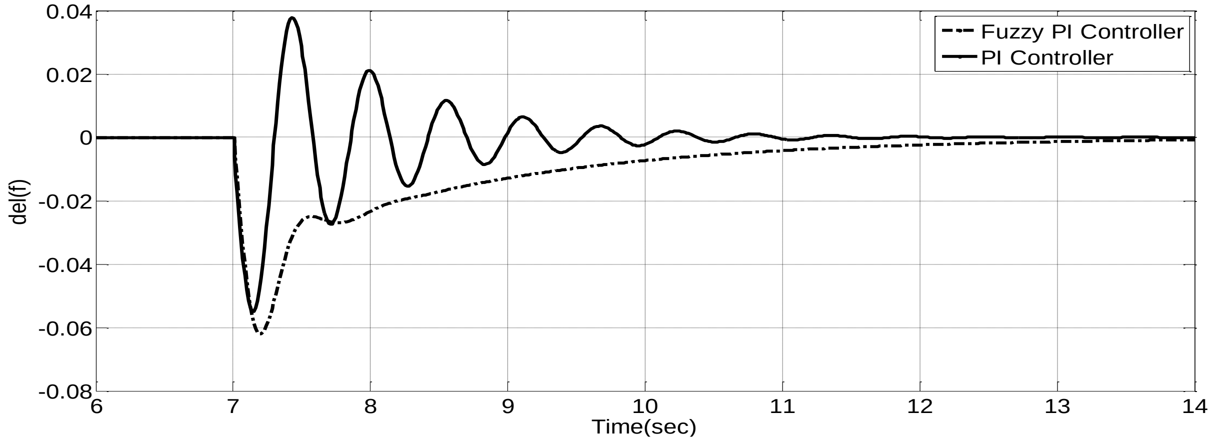

FIG 1.16: Comparison between frequency tuning in PI controller and Fuzzy PI controller of Static load

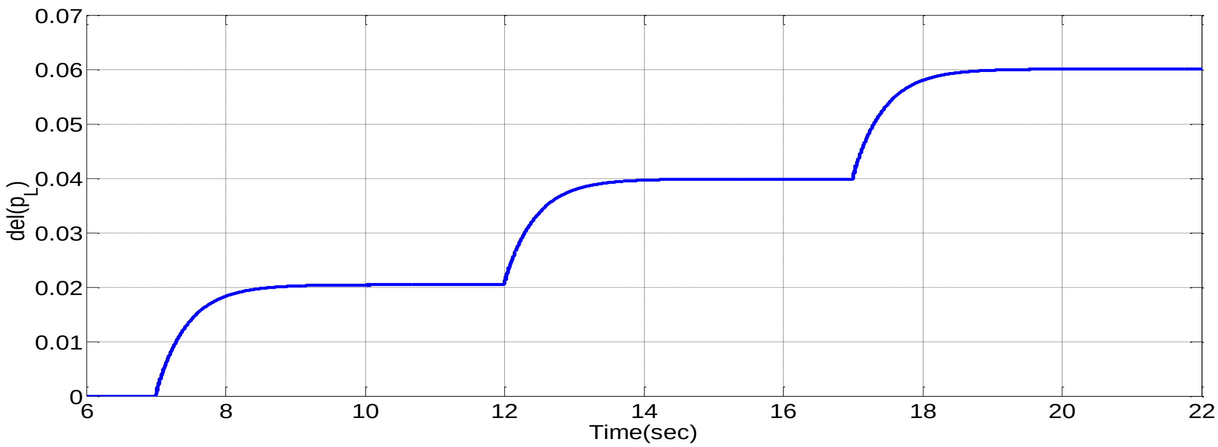

FIG 1.17: Step Response of Dynamic Load

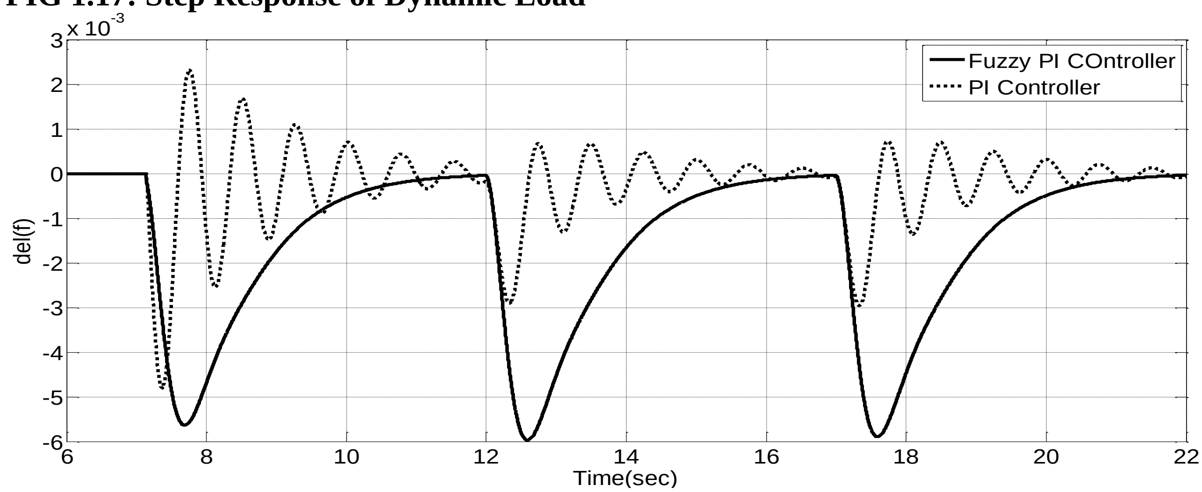

FIG 1.18: Comparison between frequency tuning in PI controller and Fuzzy PI controller of Dynamic Load

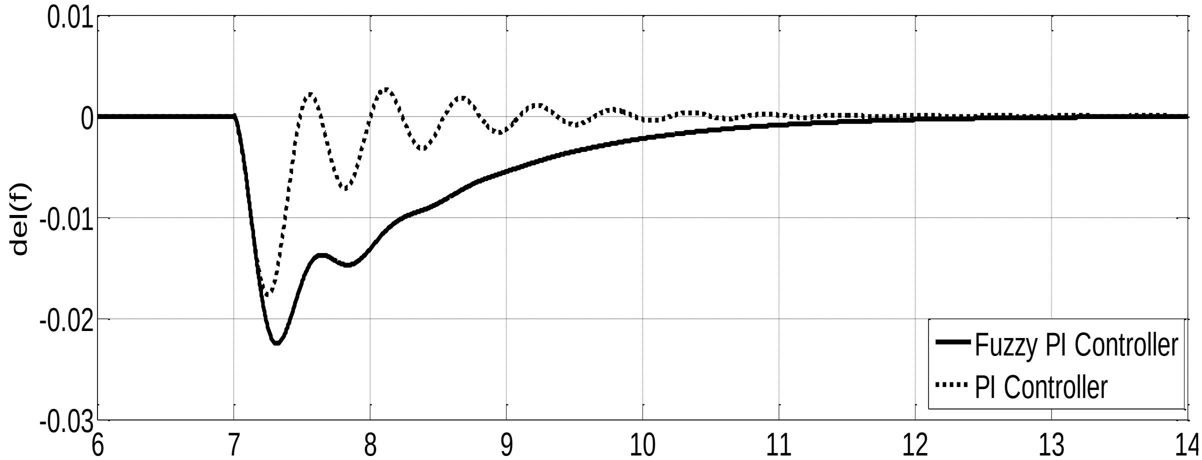

FIG 1.19: Comparison between frequency tuning in PI controller and Fuzzy PI controller of Dynamic Load for 0.1pu of change of load power

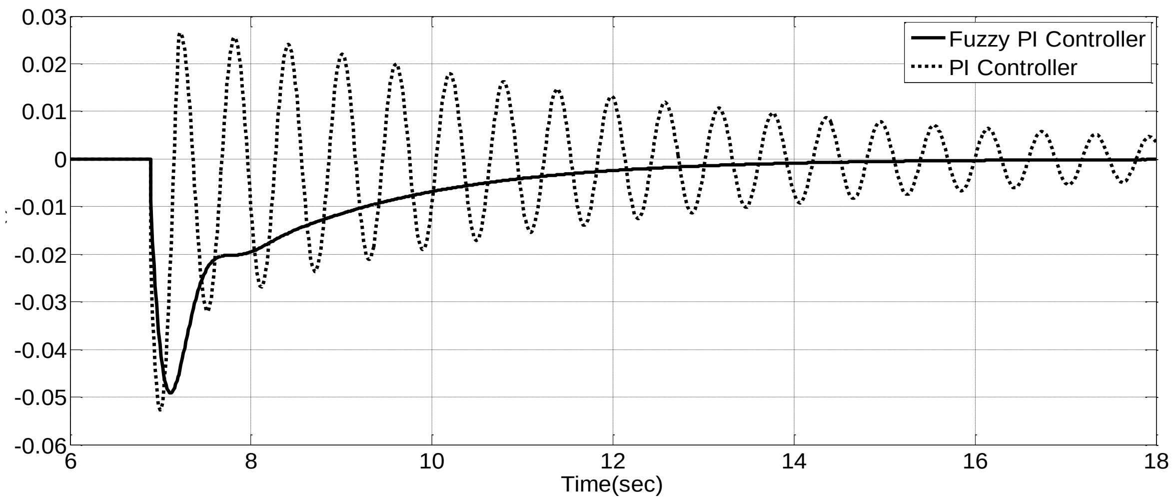

Fig1.20 Frequency tuning comparison under varying parameters

TABLE 1-7 UNCERTAIN PARAMETERS AND VARIATION RANGE

Parameter	Variation Range	Parameter	Variation Range
R	+30%	T_g	+50%
D	-40%	T_{FESS}	-45%
H	+50%	T_{BESS}	+55%
T_t	-50%		

Integral Absolute Error (IAE) and Integral Square Error (ISE) [4], [8]

$$P_{INDEX1} = \int_0^T |\Delta f| \, dt$$

$$P_{INDEX2} = \int_0^T |\Delta f|^2 \, dt$$

TABLE 1-8 CALCULATED VALUES FOR THE PERFORMANCE INDEX

Load	Performance Index Name	Conventional	Fuzzy PI
Static	IAE	0.5644	0.5236
	ISE	0.05458	0.0506
Dynamic	IAE	0.6213	0.4813
	ISE	0.054666	0.0533

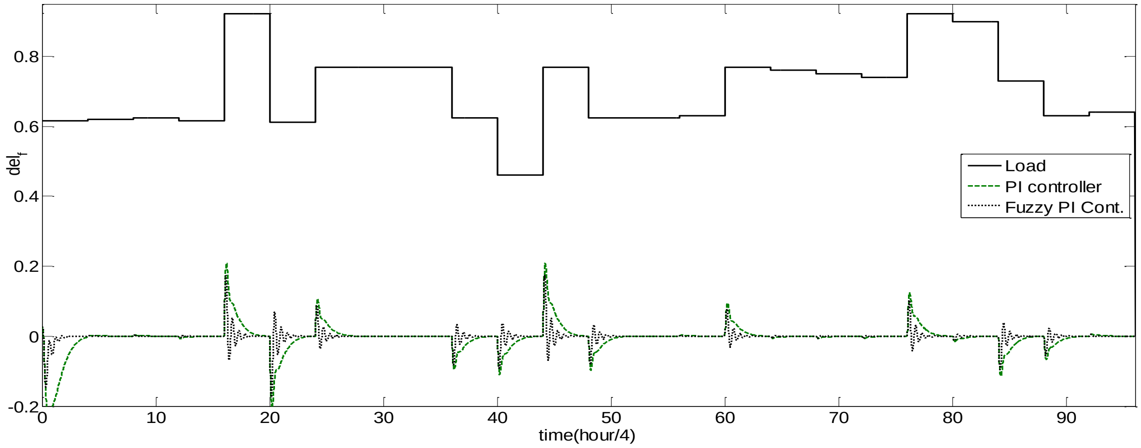

Fig1.21 Frequency tuning comparison under varying Static Load

4.2 ANALYSIS AND RESULT

It is shown in the result, the fuzzy tuned PI controller is providing better result as comparison to the conventionally tuned method, but one must keep in mind that the performance of the fuzzy has a great dependence of the membership functions. Without exact information about the whole system, it is very difficult to construct a system with proper membership functions, and if the system is not properly being studied then the designing process of the fuzzy tuned PI controller leads to malfunctions and at that time it will not provide optimal performance in various ranges. Therefore, it is always suitable to go for complementary algorithm which can be used to regulate the controller by online method with the use of membership functions. From the above figure data represented in the Fig 1.21, it is seen that, at every hour, the load is different and due to this changing of load, the deviation in the frequency is happening and for that the oscillation in the frequency occurs.

4.3 DISCUSSION

In the above figures, the comparison between the PI controller of conventional type and fuzzy PI controller is being performed and from the figures also it is clearly being stated that the fuzzy logic is providing a better result as compare to conventional one. In order to make the result more prominent the errors are taken and there also it is seen that the fuzzy logic stabilizes more in a faster way as compared to the conventional one and that's why the error is very less in fuzzy. Here the use 5^{th} order induction motor load provides a define time delay which is not being performed by the static load and this load has some short of inertia (parameters mentioned in the appendix) and due to this inertia and the system inertia making the system more and more stable and due to this the frequency is going to be stabilized in a faster way as compared to the static load and for this dynamic load the error is also less compared to the static one.

CHAPTER 5

CONCLUSION AND FUTURE WORK

Conclusion
Future Work

5.1 CONCLUSION

In this thesis, micro grids and their control have been reviewed. Frequency regulation is an essential component of ac micro-grids during the presence of disturbances and load changes. Usually, the output of a conventional PI controller varies significantly with the changes in surrounding and in presence of disturbance.

In conventional power systems, there is greater need of secondary frequency control requires and it is usually being done by using conventional PI controllers and at that time the flywheel storage system and diesel engine system need a greater role in order to stabiles the frequency. If there is a requirement of any change in the operating conditions, at that time it is difficult for the PI controllers to provide the desired performance. But, if we make the system in such a way that the PI controllers can keep a continuous track of the system changes in the power system, then the optimal performance will be always achieved in a better way. Any who Fuzzy logic can also be useful for suitable and intelligent control for online tuning of the PI controller parameters.

5.2 FUTURE WORK

- ✓ Here in this model the fuzzy PI controller is implemented and now a days many others methods are being developed. Various evolutionary algorithm like particle swarm optimization, bacteria foraging, radial basis function, and neural logic network have to be implemented.
- ✓ Here only frequency controller is being designed but in the real time when there is a power interruption both the voltage and frequency dip occur, so the use of reactive power in order to stabilize the system has to be done.
- ✓ The system model has to be in such a way that both voltage and frequency control be done at a time with a different controller not separately.

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CODES

FUZZY LOGIC CODE

```
[System]
Name='pifuzzy2'
Type='mamdani'
Version=2.0
NumInputs=2
NumOutputs=2
NumRules=18
AndMethod='min'
OrMethod='max'
ImpMethod='min'
AggMethod='max'
DefuzzMethod='centroid'
range=2;

[Input1]
Name='del_f'
Range=[-0.7 0.5]
NumMFs=6
MF1='NL':'trimf',[-0.94 -0.7 -0.46]
MF2='NM':'trimf',[-0.7 -0.46 -0.22]
```

```
MF3='NS':'trimf',[-0.46 -0.22 0.02]
MF4='PS':'trimf',[-0.22 0.02 0.26]
MF5='PM':'trimf',[0.02 0.26 0.5]
MF6='PL':'trimf',[0.26 0.5 0.74]
[Input2]
Name='del_p'

Range=[0 0.2]
NumMFs=3
MF1='S':'trimf',[-0.08 0 0.08]
MF2='M':'trimf',[0.02 0.1 0.18]
MF3='L':'trimf',[0.12 0.2 0.28]

[Output1]
Name='kp'
Range=[0 2]
NumMFs=6
MF1='NL':'trimf',[-0.4 0 0.4]
MF2='NM':'trimf',[0 0.4 0.8]
MF3='NS':'trimf',[0.4 0.8 1.2]
MF4='PS':'trimf',[0.8 1.2 1.6]
MF5='PM':'trimf',[1.2 1.6 2]
MF6='PL':'trimf',[1.8 1.9973544973545 2.25]

[Output2]
Name='output2'
Range=[0 2]
NumMFs=6
MF1='NL':'trimf',[-0.4 6.94e-018 0.4]
MF2='NM':'trimf',[0 0.4 0.8]
MF3='NS':'trimf',[0.4 0.8 1.2]
MF4='PS':'trimf',[0.8 1.2 1.6]
MF5='PM':'trimf',[1.2 1.6 2]
MF6='PL':'trimf',[1.6 2 2.]

[Rules]
1 1, 1 1 (1) : 1
2 1, 2 2 (1) : 1
3 1, 3 3 (1) : 1
4 1, 4 4 (1) : 1
5 1, 4 4 (1) : 1
6 1, 5 5 (1) : 1
1 2, 1 1 (1) : 1
2 2, 1 1 (1) : 1
3 2, 2 2 (1) : 1
4 2, 4 4 (1) : 1
5 2, 5 5 (1) : 1
6 2, 6 6 (1) : 1
1 3, 1 1 (1) : 1
2 3, 1 1 (1) : 1
3 3, 1 1 (1) : 1
4 3, 5 5 (1) : 1
5 3, 5 5 (1) : 1
6 3, 5 5 (1) : 1
```

INDUCTION MOTOR CODE

```
f=50;
```

```
ws=2*pi*f;
rs=9;
rr=11;
lm=0.7815;
lr=0.0519;
ls=lr;
p=4;
wg=0;
idr=0;
n=1000000;
wr=[];
b=0;
g=3*lm*idr;
j=
for i=0:n
    M=[ls 0 lm 0 0;
        0 ls 0 lm 0;
        lm 0 lr 0 0;
        0 lm 0 lr 0;
        0 0 0 0 j];
Z=[-rs (-ws*ls) 0 -ws*lm 0;
(ws*ls) (-rs) (ws*lm) 0 0;
0 -((ws-wr)*lm) -rr (-(ws-wr)*lr) 0;
(ws-wr)*lm 0 ((ws-wr)*lr) -rr 0;

g  -g  0  0  -b]
C=(inv(M)*Z);
D=(inv(M));
end

L2=L1;
L12=0.154;
L22=L2+L12;
L11=L1+L12;
f=50;
wo=2*pi*f
wo =
  314.1593

wr=(2*pi*1435)/60;
p=2;
ws=wo-(p*wr);
V=[537.3
0
0
0]
V =
  537.3000
         0
         0
         0
X=[rs -(wo*L11) 0 -(wo*L12)
(wo*L11) rs (wo*L12) 0
0 -(ws*L12) rr (ws*L12)
ws 0 ws*L22 rr]
X =
```

```
    1.3150  -72.8221         0  -48.3805
   72.8221    1.3150   48.3805         0
         0   -2.0965    1.1920    2.0965
   13.6136         0    3.1556    1.1920
Y=inv(X)
Y =
    0.0010   -0.0059   -0.0374    0.1051
   -0.0085    0.0066   -0.1769   -0.0346
   -0.0012    0.0294    0.0611   -0.1573
   -0.0078   -0.0101    0.2653    0.0549
I=Y*V
I =
    0.5208
   -4.5771
   -0.6595
   -4.2021
I'=V*Y
det=(L11*L22)-(L12)^2
a11=-(rs*L22)/det;
a22=a11;
a12=(wo*L11*L22)-(ws*(L12)^2);
a21=-a12;
a13=(rr*L12)/det;
a24=a13;
a14=(wo*L12*L22-ws*L12*L22)/det;
a12=((wo*L11*L22)-(ws*(L12)^2))/det;
a21=-a12;
a15=((p*L12*6.5208+L22*(-4.2021))*L12)/det;
a15=p*((L12*6.5208+L22*(-4.2021))*L12)/det;
a25=-p*((L12*6.5208+L22*(-4.2021))*L12)/det;
a15=p*((L12*(-4.5771)+L22*(-4.2021))*L12)/det;
a25=-p*((L12*(6.5208)+L22*(-0.6595))*L12)/det;
a31=(rs*L12)/det;
a42=a31;
a32=(wo*L12*L11-ws*L12*L11)/det;
a41=-(a32);
a33=(-rr*L11)/det;
a44=a33;
a34=-(wo*(L12^2)-ws*L11*L22)/det;
a43=-a34;
a35=-(p*(L12*(-4.5771)+L22*(-4.2021))*L11)/det;
a45=(p*(L12*(6.5208)+L22*(-0.6595))*L11)/det;
j=0.047;
a51=(-3*L12*(-4.2021))/j;
a52=3*L12*(-0.6595)/j;
a53=3*L12*(-4.5771)/j;
a55=0;
a54=-3*L12*6.5208/j;
b11=L22/det;
b22=b11;
b33=L11/det;
b44=b33;
b13=(-L12)/det;
b24=b13;
b31=b13;
b42=b13;
s=0.043;
```

```
N1=-(L11*(4.5771)+L12*(-4.2021));
N2=(L11*(6.5208)+L12*(-0.6595));
N3=-s*(L12*(-4.5771)+L22*(-4.2021));
N4=s*(L12*(6.5208)+L22*(-0.6595));
b16=(N3*L12-N1*L22)/det;
b26=(N4*L12-N2*L22)/det;
b36=(N1*L12-N3*L11)/det;
b46=(N2*L12-N4*L11)/det;
b12=b14=b15=b21=b23=b25=b32=b34=b35=b41=b43=b45=b51=b52=b53=b54=b56=0;
???
b12=b14=b15=b21=b23=b25=b32=b34=b35=b41=b43=b45=b51=b52=b53=b54=b56=0;
b12=b14=b15=0;
b12=b14=0
B=[b11 0 b13 0 0 b16
0 b22 0 b24 0 b26
b31 0 b33 0 0 b36
0 b42 0 b44 0 b46
0 0 0 0 b55 0]
b55=-(1/(j*det));
B=[b11 0 b13 0 0 b16
0 b22 0 b24 0 b26
b31 0 b33 0 0 b36
0 b42 0 b44 0 b46
0 0 0 0 b55 0]
B =

    7.7227         0   -5.1307         0         0    3.5665
         0    7.7227         0   -5.1307         0  -10.7009
   -5.1307         0    7.7227         0         0   -2.6809
         0   -5.1307         0    7.7227         0    6.9514
         0         0         0         0 -708.8598         0
A=[a11 a12 a13 a14 a15
a21 a22 a23 a24 a25
a31 a32 a33 a34 a35
a41 a42 a43 a44 a45
a51 a52 a53 a54 a55]
a23=0;
A=[a11 a12 a13 a14 a15
a21 a22 a23 a24 a25
a31 a32 a33 a34 a35
a41 a42 a43 a44 a45
a51 a52 a53 a54 a55]

A =
  -10.1554  551.6300    6.1158  357.4397  -17.2282
 -551.6300  -10.1554         0    6.1158   -8.7359
    6.7469  357.4397   -9.2055 -223.8572   25.9317
 -357.4397    6.7469  223.8572   -9.2055   13.1492
   41.3057   -6.4827  -44.9919  -64.0981         0
L=-(3/2)*p*L12;
C=[L*(-4.2021) L*0.6595 L*4.5771 L*6.5208 0]

C =
    1.9414   -0.3047   -2.1146   -3.0126         0

D=[0];
```

```
sys_idm = ss(A,B,C,D)
a =
           x1      x2      x3      x4      x5
   x1  -10.16   551.6   6.116   357.4  -17.23
   x2  -551.6  -10.16       0   6.116  -8.736
   x3   6.747   357.4  -9.206  -223.9   25.93
   x4  -357.4   6.747   223.9  -9.206   13.15
   x5   41.31  -6.483  -44.99   -64.1       0

b =
           u1      u2      u3      u4      u5      u6
   x1   7.723       0  -5.131       0       0   3.566
   x2       0   7.723       0  -5.131       0   -10.7
   x3  -5.131       0   7.723       0       0  -2.681
   x4       0  -5.131       0   7.723       0   6.951
   x5       0       0       0       0  -708.9       0

c =
            x1       x2       x3       x4       x5
   y1    1.941  -0.3047   -2.115   -3.013        0

d =
       u1  u2  u3  u4  u5  u6
   y1   0   0   0   0   0   0
Continuous-time model.
sys_tf = tf(sys_idm)

Transfer function from input 1 to output:
  25.84 s^4 + 1.365e004 s^3 + 6.833e006 s^2 + 2.149e009 s + 1.024e-007
-----------------------------------------------------------------------
--
s^5 + 38.72 s^4 + 4.853e005 s^3 + 1.194e007 s^2 + 3.193e010 s +
7.125e010

Transfer function from input 2 to output:
     13.1 s^4 - 3314 s^3 + 6.687e006 s^2 - 2.046e009 s + 2.373e-006
-----------------------------------------------------------------------
--
s^5 + 38.72 s^4 + 4.853e005 s^3 + 1.194e007 s^2 + 3.193e010 s +
7.125e010

Transfer function from input 3 to output:
   -26.29 s^4 - 1.22e004 s^3 - 7.84e006 s^2 - 2.302e009 s + 1.546e-006
-----------------------------------------------------------------------
--
s^5 + 38.72 s^4 + 4.853e005 s^3 + 1.194e007 s^2 + 3.193e010 s +
7.125e010

Transfer function from input 4 to output:
     -21.7 s^4 + 6846 s^3 - 8.067e006 s^2 + 2.573e009 s - 2.595e-006
--------------------------------
--------------------------------
s^5 + 38.72 s^4 + 4.853e005 s^3 + 1.194e007 s^2 + 3.193e010 s +
7.125e010
```

```
Transfer function from input 5 to output:
         8.877e004 s^3 + 2.077e007 s^2 + 2.84e010 s + 2.374e012
----------------------------------------------------------------------
s^5 + 38.72 s^4 + 4.853e005 s^3 + 1.194e007 s^2 + 3.193e010 s +
7.125e010

Transfer function from input 6 to output:
  -5.089 s^4 + 1.095e004 s^3 - 5.739e006 s^2 + 3.847e009 s - 2.882e-007
```

Appendix

Parameters of the 100HP induction machine

Pole=4; V =460V; Rated Speed=1700 rpm, Rs =0.031 ohm; R_r =0.134 ohm;
L_s=L_r=0.0193 henry; L_m=0.0189 henry; H=3.449 kg.m^2; D=0.121 N.m

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